# Spectrum-Efficient Service Provisioning in Elastic Optical Networks with Photonic Firewalls

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## Abstract

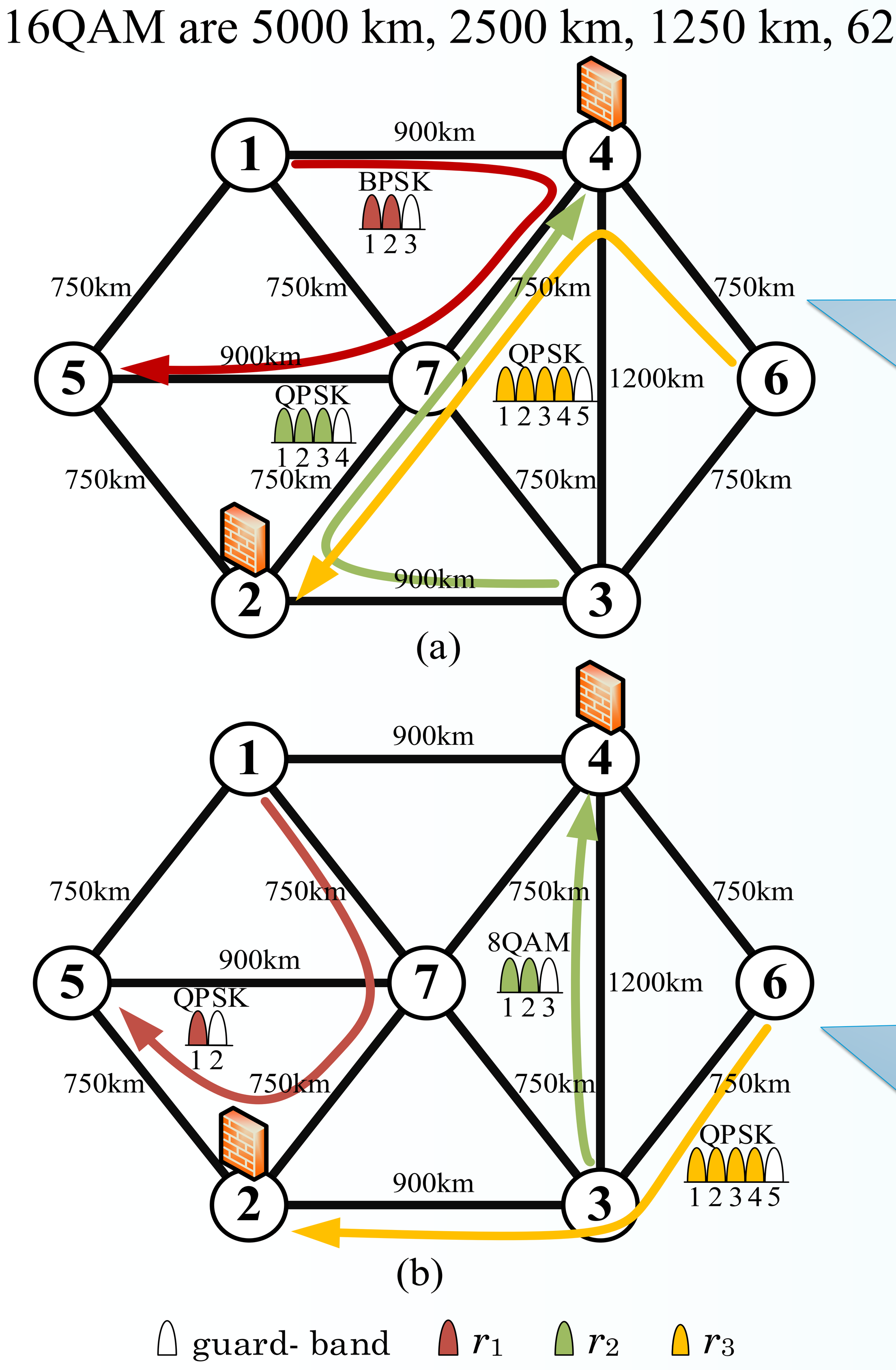
We study the routing, modulation-level and spectrum allocation for elastic optical networks with photonic firewalls. An integer linear program and a heuristic algorithm are developed. The results show the proposed algorithm achieves spectrum-efficient service transmission.

## Motivation

- Flexible-grid elastic optical networks (EONs) have become a promising technology to achieve efficient and agile access to the massive bandwidth in optical fibers.
- Optical networks are still highly vulnerable to eavesdropping and attacks due to wide coverage and quality of transmission sensitivity.
- Photonic firewall that can filter network traffic with high data rates without optical-electrical-optical conversion, and provide flexible traffic controls and filtering rules without compromising performance has been proposed to tackle security issues in optical domain.
- To ensure the security transmission, a restricted communication scenario is considered where a service request needs to be transmitted through at least one node where the photonic firewall is deployed.

## The O-PFS Scheme

A service request is denoted as $r$ ($s_r$, $d_r$, $b_r$), where $s_r$ is the source node, $d_r$ is the destination node, and $b_r$ is the capacity requirement in Gbps. There are three service requests: $r_1$ (1, 5, 20), $r_2$ (3, 4, 60), and $r_3$ (6, 2, 100). A frequency slot (FS) can support a capacity of 12.5 Gbps when modulation-level BPSK is employed. The modulation-level can be selected from BPSK, QPSK, 8QAM and 16QAM. The maximum transmission reaches of modulation-level BPSK, QPSK, 8QAM and 16QAM are 5000 km, 2500 km, 1250 km, 625 km, respectively.




Consumed FSs: 3×3+ 4×3+ 5 ×3=36; Maximum index of used frequency slot (MSI): 8.

Consumed FSs: 2×3+ 3×1+ 5×2=19; Maximum index of used frequency slot (MSI): 5.

Fig. 1. Different routing strategies for an EON with photonic firewalls: (a) S-PFS scheme, (b) O-PFS scheme.

## Heuristic Algorithm

The heuristic O-PFS algorithm first tries to calculate $|F|$ candidate light-paths for each service request. Each light-path in the candidates is the shortest path passing through a specific firewall $f$, and connecting the source and the destination. Then, the shortest light-path in the candidates is selected for the request. Next, the modulation of a light-path is determined by its length. Finally, spectrum resource is assigned.

**Input**: $G(V, E)$, $R$, $F$, $C$.
**Output**: $LP$.

**for** each request $r$ in $R$ **do**
  set $P_r = null$;
  **for** each firewall $f$ in $F$ **do**
    calculate the shortest path $P_{sf}$ connecting $s_r$ and $f$, calculate the shortest path $P_{fd}$ connecting $f$ and $d_r$, combine the paths in $P_{sf}$ and $P_{fd}$ to form a light-path $P_{sfd}$ connecting $s_r$ and $d_r$ without loop;
    check the traffic of the firewall(s) which light-path $P_{sfd}$ passes through. If the traffic amount is larger than $C$, set $P_{sfd} = null$, else add $P_{sfd}$ into $P_r$;
  **end for**
  **if** $P_r \neq null$ **do**
    select the shortest light-path $P_{rmin}$ in $P_r$;
  **else**
    block $r$, and **continue**;
  **end if**
  determine the modulation-level for $P_{rmin}$ according to its length.
  use the SWP-based spectrum allocation strategy to conduct spectrum assignment for $P_{rmin}$, add $P_{rmin}$ into $LP$.
**end for**

## Numerical Analysis

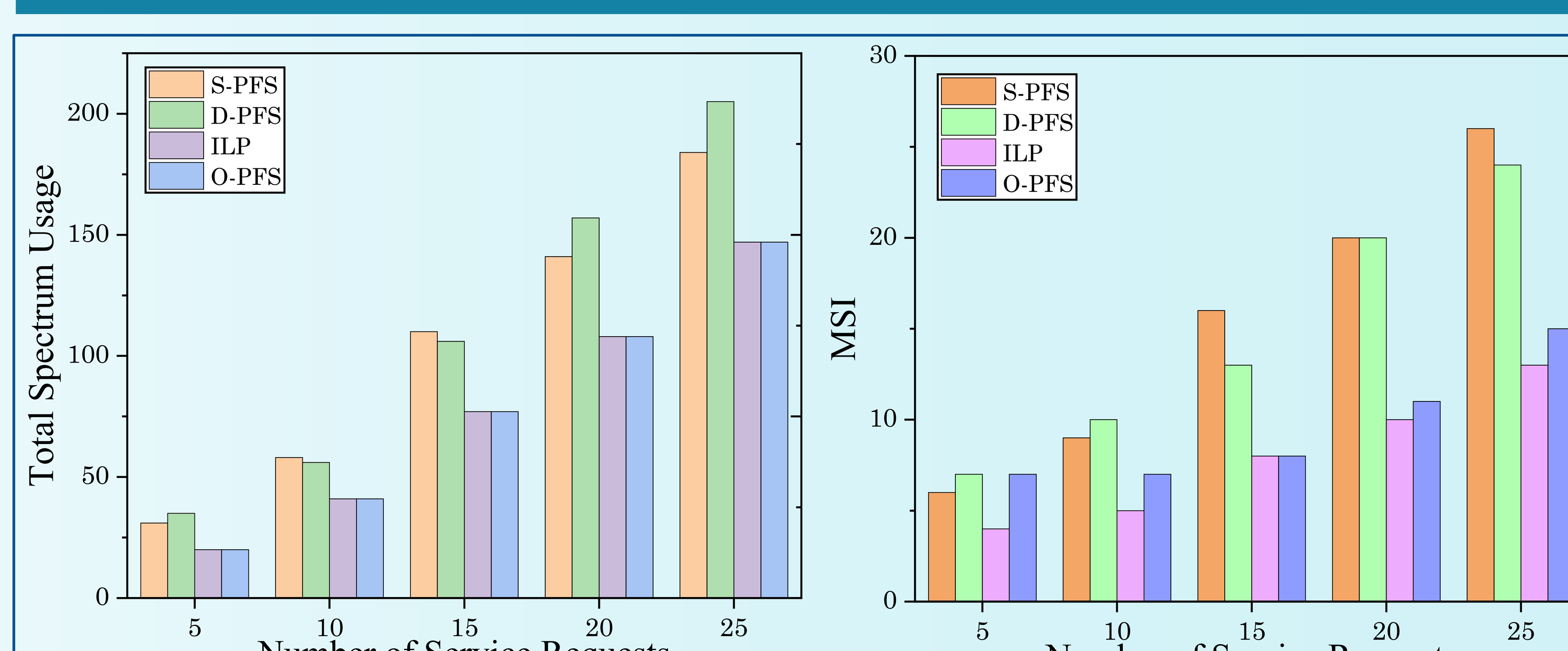



Fig. 2. Numerical results in seven-node topology: (a) the total spectrum usage, (b) the MSI.

Fig. 2 (a) shows the ILP reduces the total spectrum usage by about 25% and 30% compared with the S-PFS and D-PFS algorithms, respectively. This is because the ILP model can always select the feasible firewall for each service request, while the S-PFS or D-PFS algorithms just select the firewalls suitable to source or destination nodes. Moreover, we observe that in terms of the total spectrum usage, the performance of the O-PFS algorithm is equivalent to that of the ILP model, which illustrate the effectiveness of our proposed algorithm. In Fig. 2 (b), the ILP can reduce the MSI by about 48% and 46% compared with the S-PFS and D-PFS algorithms, respectively. Although there exists performance gap between the ILP model and the O-PFS algorithm, it is still much less than the performance gaps between the other two algorithms and the ILP model.

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